HOSPITAL PHYSICIAN®

GENERAL SURGERY BOARD REVIEW MANUAL

Blunt and Penetrating Chest Trauma: Initial Evaluation and Management

Series Editor:
Timothy A. Pritts, MD, PhD
Associate Professor, Division of Trauma and Critical Care, Department of Surgery, University of Cincinnati, Cincinnati, OH

Contributors:
Bryce RH Robinson, MD
Assistant Professor, Division of Trauma and Critical Care, Department of Surgery, University of Cincinnati, Cincinnati, OH

Nichole K. Ingalls, MD
Clinical Instructor, Division of Trauma and Critical Care, Department of Surgery, University of Cincinnati, Cincinnati, OH

Table of Contents

Blunt and Penetrating Chest Trauma: Initial Evaluation and Management

Bryce RH Robinson, MD, and Nichole K. Ingalls, MD

INTRODUCTION

Trauma is the fifth leading cause of death for all Americans and the leading cause of death for those under age 44 years.[1,2] Traumatic injuries account for 180,000 deaths and 9 million disabling injuries in the United States each year.[3] Chest trauma may result from blunt injury, such as a fall or motor vehicle crash, or penetrating trauma, such as a stab or gunshot wound. Management of blunt and penetrating trauma injuries requires expertise in rapid patient assessment, recognition of injuries, stabilization and resuscitation of patients, and provision of definitive care.

Initial management of all trauma patients is guided by the principles taught in the American College of Surgeons Committee on Trauma Advanced Trauma Life Support (ATLS) course.[4] These principles provide a common language and approach to initial evaluation and management of the injured patient. Using these guidelines, ATLS emphasizes the ABCDE approach to trauma evaluation (**Table 1**).

Chest trauma is common in injured patients and contributes to approximately 25% of trauma-related deaths.[5] Although most chest injuries can be treated with simple procedures such as tube thoracostomy, life-threatening injuries must be treated expeditiously. In the ATLS course, major chest trauma is divided into injuries that are "immediately life threatening" and those that are "potentially lethal" (**Table 2**). This approach is useful for generating a differential diagnosis and helps to guide treatment priorities for patients suffering from chest trauma.

This article provides an overview of the evaluation and management of penetrating and blunt chest trauma in the context of 2 patient presentations. Special attention is paid to specific injuries associated with chest trauma as well as the resuscitation and management of these patients.

PENETRATING THORACIC TRAUMA

CASE 1 PRESENTATION

A 17-year-old male who sustained a gunshot wound to the left chest a short time ago is brought to the emergency department by emergency medical services. Upon arrival, his airway is patent, he has diminished breath sounds over the left chest but no crepitus, and his extremities are cool and clammy. He is placed on monitors and his heart rate is 143 bpm, blood pressure is 86/palpable, respiratory rate is 28 breaths/min, and oxygen saturation is 90%. He opens his eyes to pain, is mumbling incoherently, and moves all extremities purposefully. A single bullet wound is seen in his upper left back just above the scapula.

- **What are the potential causes of this patient's shock?**

- **What are the treatment priorities?**

DIAGNOSIS AND TREATMENT OF SHOCK

The patient's clinical description suggests that he is suffering from shock. There are 4 classic shock states as defined by Blalock in 1934: hypovolemic, septic, neurogenic, and cardiac.[6] With some modifications, this basic differential diagnosis is quite useful. There are 2 categories of shock in the trauma patient—hemorrhagic and nonhemorrhagic, with hemorrhagic shock being most common. The nonhemorrhagic types of shock are cardiogenic, neurogenic, septic, and shock secondary to a tension pneumothorax.[4] Hemorrhagic shock requires rapid diagnosis and initiation of appropriate resuscitation. The other shock states require prompt intervention (ie, needle decompression and chest tube for tension pneumothorax). Potential etiologies of this patient's shock state include hemorrhage from a penetrating injury to his heart, lung, or great vessels, tension pneumothorax, and pericardial tamponade.

Table 1. ABCDEs of Initial Trauma Patient Evaluation as Guided by ATLS Principles

A:	Airway with cervical spine protection
B:	Breathing, including oxygenation and ventilation
C:	Circulation. Stop hemorrhage
D:	Disability. Rapid neurological exam
E:	Exposure/environment/avoid hypothermia

Adapted with permission from Advanced Trauma Life Support for Doctors. ATLS Student Course Manual. 8th ed. Chicago: American College of Surgeons Committee on Trauma; 2008.

Physical findings present in this patient that suggest hemorrhagic shock are tachycardia, tachypnea, and peripheral vasoconstriction (**Table 3**). A physical exam finding seen in both tension pneumothorax and pericardial tamponade is distended neck veins, and this patient's evaluation should include that assessment. This patient is unlikely to present in septic shock given his youth and presumed healthy status prior to the gun shot. Neurogenic shock can be seen with penetrating injuries to the spinal cord, but one would expect to see peripheral dilation and bradycardia.

Treatment begins with the ABCs: airway, breathing, and circulation. Priorities to address airway include administering oxygen and ensuring a patent airway. Needle decompression and then placement of a thoracostomy tube into the left thorax should be done for breathing. Obtaining large-bore peripheral intravenous (IV) access addresses circulation, and a Focused Assessment with Sonography in Trauma (FAST) exam should be performed to look for pericardial tamponade. Many of these maneuvers can be done simultaneously if enough personnel are available.

• **Which chest injuries might this patient have sustained?**

The patient has suffered a gunshot wound to the chest and may have sustained a number of chest injuries (Table 2), depending on the path of the projectile. His exam findings suggest that he likely does not have airway obstruction, open pneumothorax, or flail chest, and in light of the mechanism of injury, he likely does not have blunt cardiac injury. The patient has decreased breath sounds, suggesting the presence of tension pneumothorax, massive hemothorax, simple pneumothorax, or hemothorax. In addition, given the possible trajectory of the bullet and the presence of shock, he may be suffering from cardiac tamponade, injury to the aorta or great vessels, or injury to the mediastinal structures.

Table 2. Differential Diagnosis of Chest Injuries

Life-Threatening Injuries	Potentially Lethal Injuries
Airway obstruction	Simple pneumothorax
Tension pneumothorax	Hemothorax
Open pneumothorax	Injury to tracheobronchial tree
Flail chest	Blunt cardiac trauma
Massive hemothorax	Traumatic aortic injury
Cardiac tamponade	Mediastinal traversing wound

Adapted with permission from Advanced Trauma Life Support for Doctors. ATLS Student Course Manual. 8th ed. Chicago: American College of Surgeons Committee on Trauma; 2008.

• **How severe is this patient's hemorrhagic shock?**

Classifying hemorrhagic shock states allows the clinician to estimate the volume of blood loss and guides the resuscitation strategy. A variety of factors can confound the classic physiologic changes associated with each shock state, including patient age, home medications, anatomic location of the injury, the time from injury to presentation, and the pre-hospital medications, fluids, or other interventions.[4] The classes of hemorrhagic shock are presented in **Table 4.** Class I shock is often subtle, does not result in obvious hemodynamic changes, and is associated with blood loss of up to 750 mL in an adult. In this case, however, the patient exhibits a heart rate of greater than 140 bpm, hypotension, and tachypnea and has a markedly altered mental status. He is in class IV hemorrhagic shock, which suggests blood loss of over 2000 mL.

CASE 1 CONTINUED

The patient is placed on oxygen by face mask, and a potential tension pneumothorax is treated with needle decompression of the left chest by placing a 14-gauge angiocatheter in the second intercostal space at the midclavicular line. The nurse obtains two 14-gauge peripheral IV lines. Blood is drawn for basic laboratory studies. Point-of-care testing studies are significant for a base deficit of 16 mmol/L, lactic acid of 5 mmol/L, and an international normalized ratio of 2.2.

After the patient's left chest is prepped for thoracostomy tube placement, he loses consciousness and arrests.

• **What is the next step in the management of this patient?**

TREATMENT OF ARREST FROM PENETRATING CHEST TRAUMA

Resuscitative thoracotomy has a role in arrest from penetrating trauma. The best outcomes are seen in vic-

Table 3. Basic Physiological Changes with Classic Shock States

Type of Shock	Blood Pressure	Heart Rate	Breath Sounds	Periphery
Hemorrhagic	↓	↑	Normal	Constricted
Cardiogenic	↓	↑↓	Normal	Constricted
Neurogenic	↓	↓	Normal	Dilated
Septic	↓	↑	Normal	Dilated
Tension pneumothorax	↓	↑	Decreased	Constricted

tims of penetrating thoracic trauma who arrest in the emergency department or have cardiopulmonary resuscitation (CPR) initiated during transport but have signs of life upon arrival. These signs of life include pupillary response, spontaneous ventilation, presence of carotid pulse, measureable or palpable blood pressure, extremity movement, and cardiac electrical activity.[7] The 2001 American College of Surgeons guideline that advocates using the procedure in this population is a level II recommendation based on a systematic review of 42 studies involving nearly 7000 patients.[7] In this series, the survival rate was 11% for individuals who sustained penetrating trauma and 1.6% for those who sustained blunt trauma. The type of penetrating injury can have a profound effect on prognosis. Bullets, as opposed to knives or other objects used in stabbings, have a high kinetic energy dispersion pattern and create more destructive injuries, leading to a worse prognosis. A recent retrospective review of emergency department thoracotomy performed for cardiac or great vessel injury in 2 urban trauma centers demonstrated a 5.3% survival rate for patients who underwent a resuscitative thoracotomy.[9] This unusually low survival is explained, in part, by the high percentage of gunshot victims (88.3% of the total number of patients had cardiac or great vessel injury) and the fact that 51.6% sustained multiple gunshot injuries.[8]

Resuscitative Thoracotomy Technique

Resuscitative thoracotomy involves rapidly fashioning an anterolateral thoracotomy, evaluating and opening the pericardium, cross-clamping the aorta, then attempting to repair, at least temporarily, any injuries found. After placing endotracheal and nasogastric tubes and rapidly prepping the skin, the skin is incised at the lower border of the pectoralis major muscle (inframammary fold in women) at the level of the fourth or fifth intercostal space from the lateral aspect of the sternum continuing to the latissimus dorsi muscle laterally. The incision is carried sharply through the skin, subcutaneous tissues, chest wall muscles, and intercostal muscles over the top of the rib on the inferior aspect of the intercostal space. Once the thoracic cavity is entered, curved Mayo scissors are utilized to widely incise the intercostal muscle and pleura medially and laterally. A chest wall retractor is then placed for exposure. After the retractor is placed, the pericardium is evaluated for the presence of tamponade. If there is concern about cardiac tamponade or if CPR is necessary, the pericardium is incised anterior to the phrenic nerve, then opened widely. Subsequently, the left lung is elevated by the first assistant, allowing the operating surgeon to cross-clamp the descending aorta with a large vascular clamp. Open cardiac compressions are begun as needed and a search of the left hemithorax for injuries is undertaken. If there is a concern for bilateral injuries, the right chest may be opened in a similar fashion to complete bilateral anterolateral thoracotomies. This results in wide exposure to the structures of the chest (**Figure 1**). If an operating room is readily available, most surgeons will address injuries in a temporizing fashion until the patient can be transported to the operating room for more definitive repair.

CASE 1 CONTINUED

The operating surgeon rapidly performs a left anterolateral thoracotomy. Upon entering the chest, she notes a large amount of blood within the left chest cavity. After placing a chest retractor, she opens the pericardium anteriorly and parallel to the phrenic nerve. There is no pericardial blood. She then bluntly dissects the mediastinal pleura and guides a clamp across the thoracic aorta. The aorta feels empty. The assistant commences internal cardiac massage. The surgeon identifies ongoing rapid arterial bleeding

Table 4. Classification of Hemorrhagic Shock Based on Amount of Blood Loss

	Class I	Class II	Class III	Class IV
Blood loss (mL)	Up to 750	750–1000	1500–2000	>2000
Blood volume (%)	Up to 15	15–30	30–40	>40
Heart rate	<100	100–120	120–140	>140
Blood pressure	Normal	Normal	Decreased	Decreased
Respiratory rate	14–20	20–30	30–40	>35
Urine output (mL/hr)	>30	20–30	5–15	Negligible
Mental status	Normal	Mildly anxious	Anxious, confused	Confused, lethargic

Adapted with permission from Advanced Trauma Life Support for Doctors. ATLS Student Course Manual. 8th ed. Chicago: American College of Surgeons Committee on Trauma; 2008.

from the superior mediastinum and applies pressure. The patient regains vitals and is transported to the operating room. The surgeon identifies a proximal left carotid injury 1 cm from its aortic take-off and repairs it with an interposition graft (**Figure 2**) and also performs a small wedge resection of the left lung apex that contains a laceration. The patient is returned to the surgical intensive care unit for resuscitation.

- **How should this patient be resuscitated?**

RESUSCITATION FROM SHOCK

This patient demonstrates a marked metabolic acidosis and likely has sustained significant blood loss from his carotid artery injury. Traditionally, ATLS has taught that an initial 2000 mL bolus of crystalloid should be given to initiate resuscitation, followed by blood products if needed.[4] A new paradigm has arisen based on recent military trauma experience. Early blood product administration and a ratio of products that approximates whole blood appears to result in decreased mortality in this population. A landmark paper published by Borgman and colleagues in 2007 demonstrated that resuscitation with packed red blood cells (pRBCs) and plasma in a 1:1 ratio was associated with improved survival.[9] This strategy has been termed "damage control resuscitation," and early data have been supported by subsequent retrospective studies suggesting that minimizing crystalloid and resuscitating patients with a high ratio of plasma and platelets to pRBCs may be associated with higher survival in civilian patients as well.[9,10] This is currently a controversial topic in trauma surgery, with large prospective multicenter studies ongoing in order to clarify previous retrospective data.

- **What is the likelihood that this patient will require more than 10 units of blood in the first 24 hours?**

Although the indications for massive transfusion are still being studied in the civilian population by a multicenter trial, recent data from military trauma care suggest that a heart rate >110 bpm, systolic blood pressure <110 mm Hg, base deficit ≥ −6 mmol/L, and hemoglobin <11 g/dL are predictors that a patient may require massive transfusion.[11] In civilian centers, a simplified scoring system based on 4 parameters (penetrating mechanism, positive focused assessment with sonography for trauma for fluid, arrival blood pressure <90 mm Hg, and arrival pulse >120 bpm) has been shown to be useful in predicting which patients will require massive transfusion.[12]

- **What parameters should be used to ascertain when the patient is resuscitated?**

Shock is defined as a state of inadequate tissue oxygenation resulting in anaerobic metabolism and acidosis. Even after patients have achieved a normal blood pressure, heart rate, and urine output, up to 85% have evidence of ongoing insufficient tissue oxygenation.[13] The Eastern Association for the Surgery of Trauma guidelines recommend that the initial base deficit, gastric pH, and lactate level can be used to stratify patients with respect to risk of multisystem organ failure and death (level I recommendation). These guidelines also recommend that one should attempt to normalize the base deficit, gastric pH, and lactate level within the first 24 hours, and the inability to normalize these values should prompt evaluation for ongoing blood loss or other complications, including abdominal compartment syndrome or intestinal ischemia (level II recommendation).[13]

CASE 1 CONTINUED

The patient is resuscitated with 14 units of pRBCs, 14 units of fresh frozen plasma, 12 units of platelets, and 2 L of lactated Ringer's solution. By the next morning, his base deficit is 0.4 mmol/L and his serum lactic acid level is 1.0 mmol/L. He recovers and
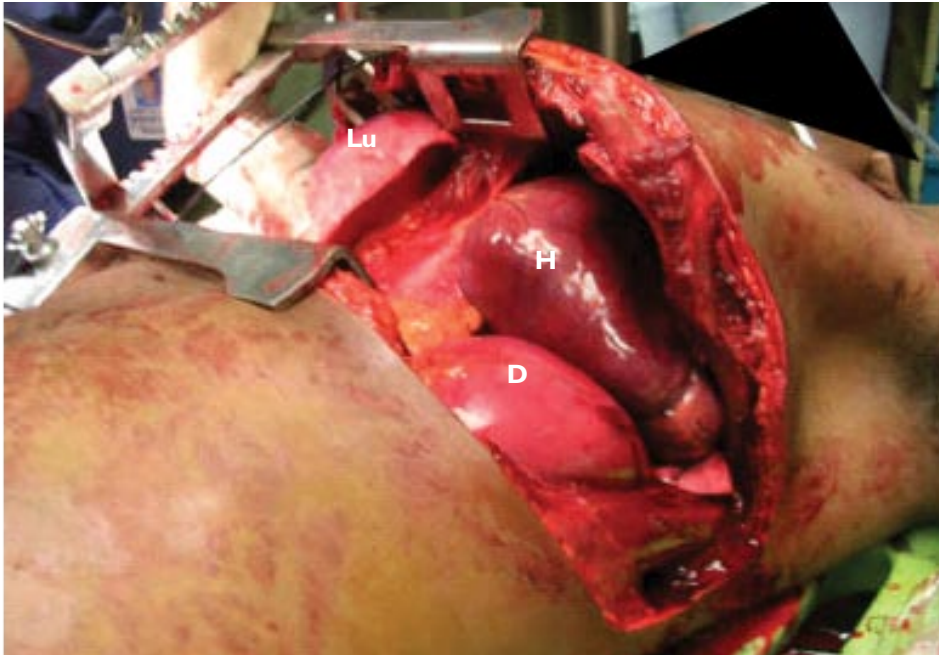
Figure 1. Postmortem view of patient who has undergone bilateral thoracotomy for resuscitation. These incisions allow extensive exposure to lungs (Lu), heart (H), as well as the mediastinum and great vessels. D = left diaphragm.

is extubated and begins enteral nutrition on postoperative day 3. The intensive care unit nurse notes that the left-sided thoracostomy tube drainage has changed in appearance. On examination, the patient states that he feels well, and he has a normal temperature and white blood cell count. On examination of the tube, the chest drainage appears to have changed from a blood-tinged clear drainage to thick white output.

- **What is the differential diagnosis?**

The 2 most likely etiologies of this type of output are chylothorax and empyema. In this patient, there are no signs of infection. He clinically looks well, is afebrile, and has a normal white blood cell count. The drainage characteristics changed with the initiation of enteral feeds, suggesting a chyle leak. The path of the bullet is consistent with injury to the thoracic duct as it passes through the superior mediastinum on its way to the left subclavian vein.[14]

CHYLE LEAK
Anatomy of the Thoracic Duct

The thoracic duct is a tubular structure that originates from the cistern chylae at the second lumbar vertebra on the right side. It enters the chest at the level of the aortic hiatus, running between the azygous vein and aorta, then crosses to the left side at the level of the fourth or fifth thoracic vertebral body, and returns lymph to the venous system at the junction of the left subclavian and jugular veins. Its course may be variable. The thoracic duct may be injured iatrogenically during operative procedures in the neck (such as radical neck dissection), chest (such as esophagectomy), and abdomen.

Treatment

The strategy of nonoperative management of a chyle leak hinges on decreasing the lymphatic flow to allow for spontaneous closure.[14] In order for healing to occur, the leak must be adequately drained, normal electrolyte and volume status must be maintained, and the patient must receive nutritional support. The nutritional plan can include either parenteral nutrition or enteral nutrition with a high percentage of medium-chain triglycerides (MCT). These MCT bypass the lymphatic system because they are readily metabolized directly into the portal venous system. These maneuvers result in fistula closure in 80% of cases.[14] The data are mixed as to whether parenteral or MCT-rich enteral feeds are best, with each having similar rates of fistula closure. Some literature suggests closure may occur more quickly if octreotide is used. The mechanism is thought to include a decrease in the absorption of
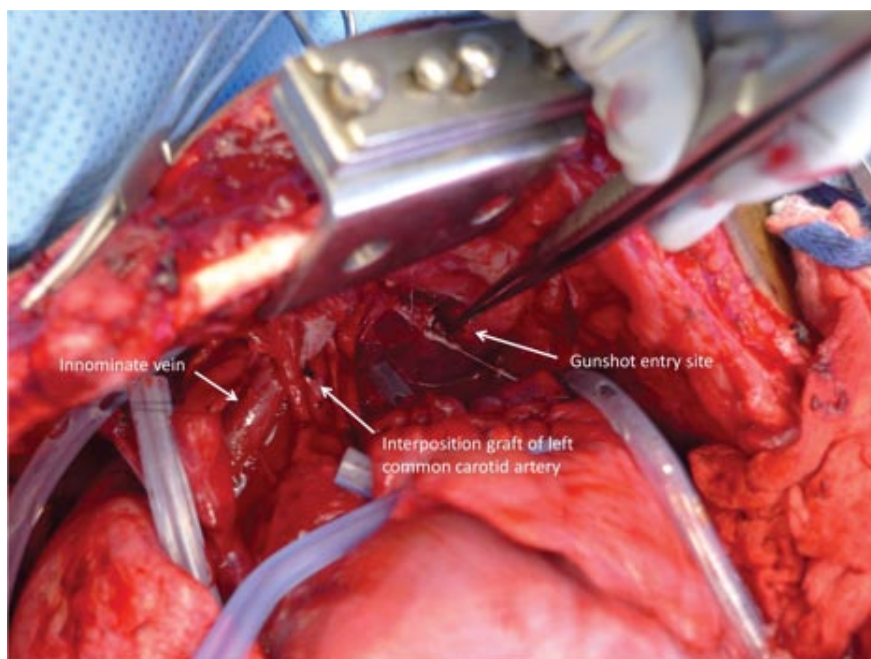
Figure 2. Intraoperative view of chest in patient presented in Case 1. The left common carotid artery was repaired with a saphenous vein interposition graft.

triglycerides with resulting decreased chyle flow. If the fistula fails to close, surgical ligation or percutaneous interventions with embolization of the thoracic duct can be attempted.

CASE 1 CONCLUSION

The patient's chyle leak appears to be low output (well less than 800 mL per day). The patient is initially made NPO, then placed on an MCT diet via a nasoenteric feeding tube. There is no increase in fistula output with enteral diet. The chylous chest tube effluent resolves after 4 days of MCT diet therapy. The patient is then restarted on a regular diet with no recurrence of the chyle leak. The chest tube is removed and the patient is discharged home on postinjury day 15.

BLUNT THORACIC TRAUMA

CASE 2 PRESENTATION

A 77-year-old man was working on a ladder when he fell 12 feet onto a large potted plant, landing on his left chest and flank. He is brought to the emergency department by the local ambulance service after being placed in a cervical collar and on a backboard.

After arrival, his initial evaluation demonstrates a primary survey that is significant for tachycardia, tachypnea, hypoxia with pulse oximetry of 84%, and palpable subcutaneous emphysema of his neck, chest, and left flank. He reports a history of hypertension, but he has initial systolic blood pressures in the mid-80s mm Hg without obvious sources of external hemorrhage. He complains of left-sided chest pain, has significant tenderness in this region with palpation, and breath sounds are absent in his left hemithorax even after prehospital personnel attempted needle thoracostomy. A chest tube is placed urgently in his left hemithorax, which produces a large rush of air and return of pulse oximetry to greater than 95%. A chest radiograph is performed after placement of the chest tube but before the secondary survey.

- **What associated injuries are probable after blunt thoracic injury?**

CLINICAL FEATURES OF BLUNT THORACIC INJURY

Approximately 25% of blunt traumatic deaths are the direct result of thoracic injury.[3] For those who survive the initial traumatic event, blunt thoracic injury is responsible for 8% of all traumatic hospital admissions.[15] Motor vehicle crashes represent the major mechanism of injury

for blunt thoracic injury for all patients. In the elderly, the most common cause of these injuries is falls.

The thorax is a mobile structure that encloses the organs of the chest by a complex interconnection of the sternum to the ribs and then to the thoracic vertebrae. When blunt force is applied to the chest, rib fractures often occur as the force is displaced along the length of the bone. In the elderly, very little force is necessary to cause rib fractures in bones that already have cortical thinning. The opposite is true in infants and children, where a great amount of force is required to cause rib fractures. These young chest walls often allow a great amount of force to be transferred internally before fracture occurs due to the mobility of a soft, cartilaginous thorax. Whether force is transferred easily through brittle ribs of the old or passively through the soft wall of the child, pulmonary contusion and cardiac and great vessel injury are potential associated injuries. These injuries may require a high index of suspicion.

The most lethal of the subtypes of pneumothorax is a tension pneumothorax, which results from air entering the chest from a lung or chest wall injury without the ability to egress. As more air enters the cavity, pressure accumulates in the chest. This intrathoracic pressure can be greater than the intrinsic venous pressure required for blood return to the heart and may displace the mediastinum. As pressure builds, there is a reduction of right heart preload as well as ipsilateral and even contralateral lung parenchymal collapse.

Hemodynamic failure and death are imminent unless the pressure is relieved. The diagnosis of tension pneumothorax is made clinically and should not be delayed by waiting for diagnostic imaging. Treatment starts with immediate chest decompression, which can be accomplished by needle thoracostomy, with placement of an IV catheter needle into the second intercostal space in the midclavicular line on the affected side. Such decompression is not without drawbacks in that it is estimated that 30% of trauma patients have a chest wall thickness greater than 5 cm, thus preventing needle decompression by commonly available angiocatheters.[16] Definitive treatment requires the expedient placement of a tube thoracostomy. The simple act of surgically entering the chest to place the tube often corrects the hemodynamic derangements.

CASE 2 CONTINUED

The chest radiograph (**Figure 3**) demonstrates a widened mediastinum, though the cardiac silhouette is normal. Extensive subcutaneous emphysema is present on both the right and left chests. Ribs 5 through 8 are fractured and the chest tube appears to be in a proper location, although a single chamber air

leak is intermittently seen. A diffuse opacity is seen in both lung fields.

On secondary survey, the patient continues to complain of significant left-sided chest pain, but he denies any other complaints. The patient has been hemodynamically stable without neurologic deficits since placement of the chest tube. A FAST exam is performed without any positive findings.

- **What further imaging may be appropriate?**

EVALUATION OF BLUNT THORACIC TRAUMA

Thoracic injuries that involve fractures of the first or second ribs, scapula and/or sternum require a great deal of force transfer. The concern is not so much for the bony injuries but rather that the force has been transferred through the bony thoracic cavity into deeper, more vital structures.[17] The presence of these fracture patterns should raise suspicion for the presence of significant chest injury that may warrant further evaluation. Such testing needs to include evaluation of the great vessels, pulmonary tree, and pulmonary parenchyma. The presence of thoracic wall fractures, whether single or multiple, often creates a distracting injury that compromises the clinician's ability to detect spine or abdominal tenderness. The presence of thoracoabdominal injuries, specifically rib fractures of the inferior rib cage, should raise concern for the possibility of intra-abdominal injuries. Computed tomography (CT) of the chest and abdomen is often the preferred method to evaluate for thoracic and abdominal injuries while maintaining the ability to specifically image retroperitoneal structures, including the thoracic and lumbar spine.[18,19] Hemodynamic stability needs to be achieved before the patient undergoes CT. If the patient is unstable for such testing, alternate means of abdominal testing (ie, FAST, diagnostic peritoneal lavage) should be performed in order to exclude intra-abdominal hemorrhage as an etiology for shock.

CASE 2 CONTINUED

Cervical plain films are negative for cervical spine fractures. CT scan of the chest demonstrates a normal appearance of the heart and great vessels (**Figure 4**). All of the ribs of the left chest are fractured, with segmental fractures at multiple concurrent levels. A lower lobe pulmonary contusion is now appreciated over the area of multiple displaced ribs. New rib fractures of the right chest along with a pneumothorax are appreciated. Abdominal CT demonstrates a grade 1 spleen laceration with minimal intra-abdominal free fluid at the injury. No other injuries are seen. The patient continues to have a Glasgow Coma Scale score

Figure 3. Initial chest radiograph of patient presented in Case 2. After needle decompression, a left chest tube was placed. Note the presence of extensive subcutaneous air bilaterally.

of 15. He is complaining of increasing shortness of breath with slight improvement with parenteral narcotics. On closer inspection, paradoxical motion of the left chest is occurring with every inspiration. The patient continues to maintain an adequate level of oxygenation by pulse oximetry with minimal supplementation of oxygen after placement of a right-sided chest tube.

- **What is a flail chest?**

- **What is the proper treatment of a flail chest?**

FLAIL CHEST AND PULMONARY CONTUSION

Rib fractures are common after blunt chest injury and have a wide spectrum of injury. Mortality has been demonstrated to be directly proportional to the number of ribs fractured.[20] Management of simple rib fractures is more complex in elderly patients. Bulger et al demonstrated that for each additional rib fracture in the elderly, mortality increases by 19% and the risk for pneumonia increases by 27%.[21] The most complex rib fracture pattern is that of a flail chest. A flail chest results from 2 or more ribs that are fractured in two or more locations, sternal fracture, or costochondral separation. The term "flail" refers to the paradoxical motion of the affected chest wall segment caused by the lack of structural integrity. During inspiration, the flail segment is drawn into the chest (due to negative intrapleural pressure), while the rest of the thorax expands outward. The opposite occurs during expiration, with the flail segment being pushed outward while the rest of the chest retracts.

The mortality and morbidity of patients with flail chest are directly proportional to the magnitude of the underlying pulmonary contusion.[22] Because the chest wall becomes unstable during impact, the moving segment directly injures the lung parenchyma deep to the thoracic wall. The resultant pulmonary contusion produces a zone of central parenchymal hemorrhage with a surrounding area of peripheral edema.[23] As fluid and blood become incorporated into the injured alveoli, gas exchange is compromised, causing a localized reduction in the partial pressure of oxygen. The area of edema increases over time as a result of direct injury rather than a downstream cytokine mechanism. Maximal edema is often seen at 24 hours, with complete loss of normal alveolar cellular architecture. This cellular mechanism is clinically appreciated as the patient continues to become progressively more hypoxic.

Patients with significant hypoxia may require intubation rapidly after injury due to the progressive nature of this process. Clinically, pulmonary contusions often progress for 48 hours after injury, with maximal ventilation-perfusion mismatching occurring during this period.[24] Elective intubation prior to respiratory failure should be considered early in the patient's management. With mechanical ventilation in place, manipulation of mean airway pressure (eg, positive end-expiratory pressure, inspiration-to-expiration ratio) should be considered to reinflate collapsed pulmonary segments and alveoli to maximize oxygenation. Nonetheless, the treatment of pulmonary contusion is entirely supportive, with resolution occurring at approximately 1 week.

CASE 2 CONTINUED

The patient is admitted to the intensive care unit for aggressive pulmonary toilet and pain control. The patient complains of severe left-sided chest pain that is relieved with nurse-provided intermittent parenteral narcotics. However, after delivery of narcotics, the patient becomes more somnolent with an increasing oxygen requirement, decreasing capacity for incentive spirometry, and worsening delirium. Restricting pain medication results in chest splinting and decreased effort for productive cough.

- **What pain alleviation techniques can be utilized to optimize pulmonary function after chest injury?**

PATIENT-CONTROLLED ANALGESIA AND REGIONAL ANESTHESIA TECHNIQUES

Although often underappreciated, the sequelae of pain from fractures of the thorax can be dramatic. The
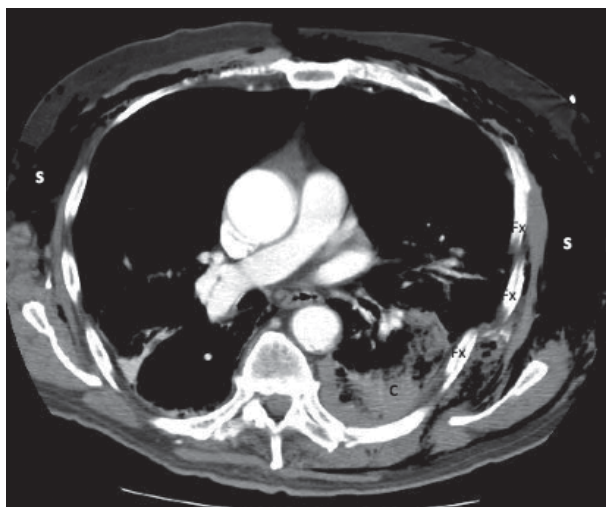
Figure 4. Chest computed tomography image of patient presented in Case 2. Extensive subcutaneous air is present (S), as are multiple rib fractures (Fx). A pulmonary contusion (C) is now present as well.

ability of patients to participate in incentive spirometry, clear secretions, ventilate, and oxygenate is compromised by such pain. Pulmonary complications and mortality in the elderly from rib fractures are likely the consequence of poor pulmonary toilet.[21,25] Patients naturally wish to splint their chest to aid in pain control, but this technique is potentially harmful given the reduced pulmonary toilet achieved with an immobile chest wall.

Pain control should be adequate in order to allow successful pulmonary toilet and is a primary goal in treatment of this patient population. Complications of hypoventilation, retained secretions, pneumonia, atelectasis and respiratory failure have been associated with inadequate pain control.[26] Commonly, trauma patients receive pain delivery by parenteral or enteral means. Regional techniques, which include epidural delivery, and local techniques, including nerve blocks, intrapleural catheters, and extrapleural, are increasingly being used. These techniques can be controlled by the care team or by the patient via a patient-controlled analgesia (PCA) device.[27] Patient-controlled devices prevent breakthrough pain and reduce the risk of oversedation, which can contribute to a delay in pulmonary toilet, atelectasis, and cough.

CASE 2 CONTINUED

After 24 hours of epidural catheter pain control, the patient fails to progress and is becoming progressively more hypoxic. He is electively intubated and placed on a spontaneous mode of ventilation with positive end-expiratory pressure titrated to reduce the paradoxical motion of his left chest. Daily spontaneous breathing trials are attempted on hospital days 3 and 4 without success for extubation. Reasons for these failures are examined, with concerns raised over retained hemothorax in the left chest contributing to atelectasis seen on daily chest radiograph and displaced rib fractures contributing to significant pain.

- **What interventions are available to facilitate the success of liberation from mechanical ventilation?**

INTERVENTIONS FOR RETAINED HEMOTHORAX AND RIB FRACTURES

Hemothorax after blunt thoracic injury is a common occurrence, though most cases are successfully treated with placement of a large-bore tube thoracostomy (32Fr to 36Fr). A minority of patients (5%–30%) fail to clear clot from their chest, raising concerns over the eventual development of a restrictive fibrothorax, empyema, or pulmonary entrapment.[28–30] Treatment relies heavily on the accurate diagnosis of such a process. Historically, chest radiography was the diagnostic study of choice, although the accuracy of such imaging is questioned. Recent data suggest that CT scan is more accurate than chest radiograph for diagnosis of retained hemothorax. In a study of patients with traumatic hemothorax who underwent a second chest radiograph and CT on the second day after admission, Velmahos et al demonstrated that the surgeon's and radiologist's chest radiograph interpretations were incorrect (ie, > 300 mL difference between the 2 readings) in 48% and 47% of the cases, respectively.[31] Management of 31% of these cases would have occurred incorrectly had the chest radiograph alone been used, thus supporting CT as the initial test of choice. Clot volume can be accurately calculated from CT, although the volumes at which interventions are initiated have not been objectively determined.[32] Nonetheless, volumes between 300 mL and 500 mL are often used as the threshold for intervention.

The optimal intervention for retained hemothorax is also controversial. Successful intrapleural thrombolysis by infusion of thrombolytic agents into the chest thoracostomy tubes has been reported.[33,34] Advocates of surgical intervention, specifically video-assisted thoracoscopy (VATS), stress the accuracy, safety, and reliability of such an intervention along with the reduced duration for tube thoracotomy, and even a cost benefit due to a reduced length of stay.[35–37] When these interventions are compared across the small body of

existing literature, a reduced length of hospital stay as well as fewer therapeutic failures, defined as need for thoracotomy, is shown in those receiving early VATS.[38] The benefit of VATS is clearly dependent on the timing of the intervention after injury. It appears that the rate of complication with VATS therapy escalates after injury day 3 to 5.[39]

The surgical treatment of rib fractures may be indicated in certain circumstances. Operative indications for rib plating are evolving and consensus has not yet been reached. Proponents suggest rib plating for flail chest, painful, moveable rib fractures refractory to traditional pain management, chest wall deformity, rib nonunion, and respiratory failure.[40,41] Long-term studies regarding outcomes are anticipated.

CASE 2 CONCLUSION

Given the patient's age and risk of prolonged mechanical ventilation, the amount of retained hemothorax quantified on chest CT, and the significant bony displacement, the patient is deemed a candidate for VATS and operative rib plating. He undergoes the procedure on hospital day 5 with success. By hospital day 7, he is extubated and his tube thoracostomies are removed. Pain continues to be a problem, with the patient requiring long-acting enteral narcotics as he transitions to a physical rehabilitation center on hospital day 9.

SUMMARY POINTS

- Chest injuries are common in trauma patients.

- Initial evaluation and management follows the ABCDEs of ATLS.

- Understanding, recognizing, and treating shock are essential in caring for patients with thoracic trauma.

- Care of patients with blunt thoracic trauma may require pain control and extensive ventilatory management.

REFERENCES

1. Centers for Disease Control and Prevention. Web-based injury statistics query and reporting system. 2010
2. Heron M. Deaths: leading causes for 2004. Natl Vital Stat Rep 2007;56:1–95.
3. Calhoon JH, Trinkle JK. Pathophysiology of chest trauma. Chest Surg Clin N Am 1997;7:199–211.
4. Adapted with permission from Advanced Trauma Life Support for Doctors. ATLS Student Course Manual. 8th ed. Chicago: American College of Surgeons Committee on Trauma; 2008.
5. Yamamoto L, Schroeder C, Morley D, Beliveau C. Thoracic trauma: the deadly dozen. Crit Care Nurs Q 2005;28:22–40.
6. Brooks B, Blalock A. Shock with particular reference to that due to haemorrhage and trauma to muscles. Ann Surg 1934;100:728–33.
7. Working Group, Ad Hoc Subcommittee on Outcomes, American College of Surgeons. Committee on Trauma. Practice management guidelines for emergency department thoracotomy. J Am Coll Surg 2001;193:303–309.
8. Seamon MJ, Shiroff AM, Franco M, et al. Emergency department thoracotomy for penetrating injuries of the heart and great vessels: an appraisal of 283 consecutive cases from two urban trauma centers. J Trauma 2009;67:1250–8.
9. Borgman MA, Spinella PC, Perkins JG, et al. The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital. J Trauma 2007;63:805–13.
10. Stansbury LG, Dutton RP, Stein DM, et al. Controversy in trauma resuscitation: do ratios of plasma to red blood cells matter? Transfus Med Rev 2009;23:255–65.
11. Larson CR, White CE, Spinella PC, et al. Association of shock, coagulopathy, and initial vital signs with massive transfusion in combat casualties. J Trauma 2010;69 Suppl 1:S26–32.
12. Cotton BA, Dossett LA, Haut ER, et al. Multicenter validation of a simplified score to predict massive transfusion in trauma. J Trauma 2010;69 Suppl 1:S33–39.
13. Tisherman SA, Barie P, Bokhari F, et al. Clinical practice guideline: endpoints of resuscitation. J Trauma 2004;57:898–912.
14. Smoke A, Delegge MH. Chyle leaks: consensus on management? Nutr Clin Pract 2008;23:529–32.
15. Peterson RJ, Tepas JJ, 3rd, Edwards FH, et al. Pediatric and adult thoracic trauma: age-related impact on presentation and outcome. Ann Thorac Surg 1994;58:14–18.
16. Ball CG, Wyrzykowski AD, Kirkpatrick AW, et al. Thoracic needle decompression for tension pneumothorax: clinical correlation with catheter length. Can J Surg;53:184–8.
17. Brown CV, Velmahos G, Wang D, et al. Association of scapular fractures and blunt thoracic aortic injury: fact or fiction? Am Surg 2005;71:54–7.
18. Diaz JJ, Jr., Cullinane DC, Altman DT, et al. Practice management guidelines for the screening of thoracolumbar spine fracture. J Trauma 2007;63:709–18.
19. Hoff WS, Holevar M, Nagy KK, et al. Practice management guidelines for the evaluation of blunt abdominal trauma: the East practice management guidelines work group. J Trauma 2002;53:602–15.
20. Flagel BT, Luchette FA, Reed RL, et al. Half-a-dozen ribs: the breakpoint for mortality. Surgery 2005;138:717–23.
21. Bulger EM, Arneson MA, Mock CN, Jurkovich GJ. Rib fractures in the elderly. J Trauma 2000;48:1040–6.
22. Trinkle JK, Richardson JD, Franz JL, et al. Management of flail chest without mechanical ventilation. Ann Thorac Surg 1975;19:355–63.
23. Fulton RL, Peter ET. Compositional and histologic effects of fluid therapy following pulmonary contusion. J Trauma 1974;14:783–90.
24. Virgilio RW, Rice CL, Smith DE, et al. Crystalloid vs. colloid resuscitation: is one better? A randomized clinical study. Surgery

1979;85:129–39.

25. Bergeron E, Lavoie A, Clas D, et al. Elderly trauma patients with rib fractures are at greater risk of death and pneumonia. J Trauma 2003;54:478–85.

26. Desai PM. Pain management and pulmonary dysfunction. Crit Care Clin 1999;15:151–66.

27. White PF. Use of patient-controlled analgesia for management of acute pain. JAMA 1988;259:243–7.

28. Mancini M, Smith LM, Nein A, Buechter KJ. Early evacuation of clotted blood in hemothorax using thoracoscopy: case reports. J Trauma 1993;34:144–7.

29. Eddy AC, Luna GK, Copass M. Empyema thoracis in patients undergoing emergent closed tube thoracostomy for thoracic trauma. Am J Surg 1989;157:494–7.

30. Coselli JS, Mattox KL, Beall AC, Jr. Reevaluation of early evacuation of clotted hemothorax. Am J Surg 1984;148:786–90.

31. Velmahos GC, Demetriades D, Chan L, et al. Predicting the need for thoracoscopic evacuation of residual traumatic hemothorax: chest radiograph is insufficient. J Trauma 1999;46:65–70.

32. Mergo PJ, Helmberger T, Didovic J, et al. New formula for quantification of pleural effusions from computed tomography. J Thorac Imaging 1999;14:122–5.

33. Kimbrell BJ, Yamzon J, Petrone P, et al. Intrapleural thrombolysis for the management of undrained traumatic hemothorax: a prospective observational study. J Trauma 2007;62:1175–8.

34. Skeete DA, Rutherford EJ, Schlidt SA, et al. Intrapleural tissue plasminogen activator for complicated pleural effusions. J Trauma 2004;57:1178–83.

35. Meyer DM, Jessen ME, Wait MA, Estrera AS. Early evacuation of traumatic retained hemothoraces using thoracoscopy: a prospective, randomized trial. Ann Thorac Surg 1997;64:1396–1400.

36. Heniford BT, Carrillo EH, Spain DA, et al. The role of thoracoscopy in the management of retained thoracic collections after trauma. Ann Thorac Surg 1997;63:940–3.

37. Landreneau RJ, Keenan RJ, Hazelrigg SR, et al. Thoracoscopy for empyema and hemothorax. Chest 1996;109:18–24.

38. Oguzkaya F, Akcali Y, Bilgin M. Videothoracoscopy versus intrapleural streptokinase for management of post traumatic retained haemothorax: a retrospective study of 65 cases. Injury 2005;36:526–9.

39. Vassiliu P, Velmahos GC, Toutouzas KG. Timing, safety, and efficacy of thoracoscopic evacuation of undrained post-traumatic hemothorax. Am Surg 2001;67:1165–9.

40. Nirula R, Diaz JJ, Jr., Trunkey DD, Mayberry JC. Rib fracture repair: indications, technical issues, and future directions. World J Surg 2009;33:14–22.

41. Nirula R, Mayberry JC. Rib fracture fixation: controversies and technical challenges. Am Surg;76:793–802.